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ORIGINAL CONTRIBUTION

Evaluation of novel semiochemical dispensers simultaneously releasing pear ester and sex pheromone for mating disruption of codling moth (Lepidoptera: Tortricidae)

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Abstract

The performance of polyvinyl chloride polymer (PVC) dispensers loaded with two rates of ethyl (*E,Z*)-2,4-decadienoate (pear ester) plus the sex pheromone, (*E,E*)-8,10-dodecadien-1-ol (codlemone) of codling moth, *Cydia pomonella* (L.), was compared with similar dispensers and two commercial dispensers (Isomate® and CheckMate®) loaded only with codlemone. Dispenser evaluations were conducted in replicated small (0.1 ha) and large (2 ha) field trials in apple, *Malus domestica* (Borkhausen), during 2006 (Washington) and 2007 (Michigan, large plot study only). Data recorded included male captures in traps baited with virgin female moths and codlemone lures and direct observations of moth behaviour in treated plots. Volatile air collections of field-aged dispensers were conducted under laboratory conditions. Disruption of male catch in codlemone-baited traps was generally similar among dispenser treatments, except for two instances: lower moth catches with the single and dual-component PVC dispensers, compared with Isomate®, during the first flight in the large plots in Michigan in 2007 and for the dual-component PVC dispenser compared with the CheckMate® dispenser during the second flight in small plots in Washington in 2006. Levels of fruit injury were similar in large plots treated with all dispensers. Male moth catches in virgin female-baited traps did not differ among dispenser treatments and were significantly lower than the untreated control. Behavioural observations of adult moths in the field verified anemotactic approaches within 20 cm of pheromone dispensers loaded with and without pear ester that lasted *ca*. 15 s on average. Field-aged dual-component dispensers released pear ester at a >5-fold higher rate than codlemone over the first 8 weeks and this ratio declined to near unity by 18 weeks.

Introduction

Pear ester, ethyl (*E, Z*)-2,4-decadienoate, a characteristic ripe odour from pear, *Pyrus communis* L., elicits a strong behavioural attraction in adult and larval codling moth, *Cydia pomonella* (L.) (Knight and Light 2001; Light et al. 2001). Antennae of both male and female adults have large numbers of olfactory receptors tuned for pear ester and other cells that respond to both its sex pheromone, (*E,E*)-8,10-dodecadien-1-

ol (codlemone) and pear ester (De et al. 2004; Ansebo et al. 2005). Combining pear ester with codlemone can create a more effective male lure (Knight et al. 2005), and the use of pear ester has been particularly useful for monitoring sex pheromone-treated orchards (Knight and Light 2005). More recently, the use of pear ester plus acetic acid was found to be an effective non-pheromone lure that can enhance growers' ability to monitor female moths (Landolt et al. 2007; Knight 2010). The attraction of *C. pomonella* larvae to pear ester has been used to improve the efficacy of some insecticides by increasing wandering time and exposure to residues prior to fruit penetration (Arthurs et al. 2007; Light 2007; Schmidt et al. 2008; Light and Beck 2010).

Mating disruption for *C. pomonella* management is practiced on approximately 160,000 ha of tree fruit crop worldwide (Witzgall et al. 2008). Although this insect control tactic can be highly effective for managing this pest, results remain variable and continued improvement of mating disruption technology is needed for this environmentally sound approach to remain cost competitive with newer and more selective insecticide chemistries (Witzgall et al. 2008). The consistency of *C. pomonella* mating disruption could be improved with more effective active ingredients and/or release technologies. Host plant volatiles are known to synergize the response of male *C. pomonella*, as well as other lepidopteran species, to their female sex-attractant pheromones (Light et al. 1993; Landolt and Phillips 1997; Reddy and Guerrero 2004). A recent review of *C. pomonella* chemical ecology and management suggested that investigating the interaction of pheromone and plant volatiles for semiochemical-based management of *C. pomonella* should be pursued (Witzgall et al. 2008). Semiochemical formulations that simultaneously release pheromone and host-plant volatiles may improve mating disruption of *C. pomonella* and other lepidopteran species currently managed by formulations that release only pheromone. For *C. pomonella*, the pear ester is a logical candidate host-plant volatile for testing to improve mating disruption based on its broad behavioural activity on this species detailed above.

Herein, we report on investigations conducted in Washington and Michigan, U.S.A., which evaluated the effectiveness of a new polyvinyl chloride polymer dispenser loaded with both pear ester and codlemone to disrupt sexual communication compared with similar dispensers loaded with only codlemone, and with two commercial sex pheromone dispensers. In addition, the behavioural response of male moths to dispensers in the field as well as the emission characteristics of these dispensers was analysed to gain insights into possible mechanisms of disruption.

Materials and Methods

Dispensers

Investigations were conducted with several experimental and commercial dispensers loaded with either codlemone alone or a blend of codlemone and pear ester. Experimental dispensers (Trécé Inc., Adair, OK) were constructed of a proprietary, polyvinyl chloride (PVC) polymer. TRE 9923 was loaded with 128.4 mg codlemone. The dual-component dispensers TRE 9940 and TRE 9904 were loaded with 73.2 and 108.6 mg, and 139.2 and 200.4 mg of codlemone and pear ester, respectively. The effectiveness of these dispensers was compared with two commercial products: the polyethylene reservoir dispenser, Isomate®-C Plus (Pacific Biocontrol, Vancouver, WA) loaded with 96.5 mg and the plastic membrane dispenser, CheckMate® CM (Suterra LLC, Bend, OR) loaded with 180.0 mg of codlemone.

Small plot study

Experiments were conducted in replicated 0.1 ha plots in an unmanaged apple orchard [mix of 'Delicious' and 'Golden Delicious' situated near Wapato, WA (46.45°N, 120.42°W) during 2006. Trees were planted at a density of 427 per ha and canopy height averaged 4.6 m. Treatments included four replicates of an untreated control, two experimental PVC dispensers (TRE 9923 and TRE 9904), and CheckMate® CM (Suterra LLC). TRE 9923 was tested at 1000 dispensers per ha and CheckMate® CM was tested at 500 dispensers per ha. The dual-component PVC dispenser (TRE 9904) was tested at two rates, 500 and 1000 dispensers per ha. Five replicates of each treatment were randomized and plots were spaced 20–30 m apart. Dispensers were placed in the upper third of the canopy of each plot on 24 May. A single white, delta-shaped trap (Trécé Inc.) baited with a commercial sex pheromone lure (PHEROCON® L2; Trécé Inc) was placed in the centre of each plot and hung at 2.0 m. The codlemone-baited trap was checked and sticky liners were replaced weekly. Lures were replaced after 8 weeks. In addition, five white, delta-shaped traps baited with two virgin female moths housed inside of a screened plastic cylinder hanging from the inside top of the trap were spaced 10–20 m from the centre trap and placed at 3.0–3.5 m in the canopy. The lure-baited trap at the centre of each plot was placed at the lower height to minimize its competitive interaction with female-baited traps. Unsexed moths were collected from the codling moth mass-rearing facility at the Yakima Agricultural Research Service Laboratory in Wapato, WA on Monday of each week, sexed, and stored in plastic crispers at 5°C. Screened cylinders were loaded with two female moths on Tuesday and held at 5°C. Female-loaded cylinders were taken to the field and loaded in traps on Wednesday of each week. However, only subsets of these data were included in the subsequent analyses. Data for male catches in the virgin female baited-traps were only included in the analysis when moths were observed to be active for at least 3 days following trap application. This data subset was restricted to male moth catches for 5 and 6 weeks during the first and second moth flight period, respectively. The study was conducted from 25 May to 5 September. Data were summarized for each flight period based on accumulated degree days from the start of male moth flight (Knight 2007).

Large plot studies

Similar studies were conducted in commercial apple orchards in both Washington and Michigan to evaluate PVC dispensers and compare their performance against Isomate®-C Plus in replicated 2-ha plots. Experiments in Washington were conducted near Brewster, (48.10°N, 119.78°W) in six 16-ha blocks of 'Granny Smith' and 'Fuji' from 5 May to 12 September. Trees were planted at densities of 427–561 per ha and canopy heights ranged from 4.0 to 5.5 m. Studies in Michigan were conducted in 'Red Delicious' orchards situated near Grand Rapids (42.94°N, 85.64°W) from 18 May to 10 September. Trees were planted at 441 trees per ha with canopy heights of 4.9 to 5.5 m. Plots in both states were separated by >0.5 ha buffers. All dispensers were applied in late April to early May at 1000 per ha. Treatments included in the Washington study were six replicates of Isomate®-C Plus and TRE 9904, and three replicates of TRE 9923 and TRE 9940. The study in Michigan included four replicates of Isomate®-C Plus, TRE 9904 and TRE 9923, as well as, an untreated control (no dispensers). All dispensers were applied by hand to the upper third of the tree canopies. Plots within each block were also treated with identical insecticide programs to prevent unacceptable levels of fruit damage at harvest. Plots in Washington were treated with three applications of azinphos-methyl at 2.2 kg and two sprays of acetamiprid at 238 g/ha. Plots in Michigan were sprayed with two applications of azinphos-methyl at 2.2 kg and thiocloprid at 0.43 l/ha. Plots in Washington were monitored with two delta-shaped traps baited with PHEROCON® L2 lures and spaced 30 m apart in the central area of each plot. Michigan plots were monitored with 10 similar traps. Michigan traps within each plot were spaced 6–20 m apart depending on the geometry of the plot and >15 m from borders. Traps were checked each week and lures were replaced after 8 weeks. The experiment in Washington was conducted from 30 April to 23 September and in Michigan from 18 May to 10 September. Fruit injury was assessed in both studies at mid-season (July) and pre-harvest (September) by inspecting 30 randomly-selected fruit (15 high and 15 low in the canopy) from each of 20 randomly-selected trees per replicate treatment plot.

Field observations of moth approach to dispensers

Experiments were conducted in the spring and summer of 2006 within 16 tree plots (0.07 ha) of 21-year-old Delicious apple trees with *ca.* 2.5–4.5 m canopy heights at the Trevor Nichols Research Complex (TNRC) of Michigan State University in Fennville, MI. Trees were planted on a 3 m within- and 6 m between-row spacing. Plots were pruned and received fungicide and herbicide applications according to growers' standards in Michigan, but did not receive insecticide applications. The dispenser treatments deployed for observation were TRE 9923 (codlemone only), TRE 9904 (codlemone + pear ester) and Isomate®-C Plus. All pheromone dispenser treatments were applied at an equivalent rate of 1000 units per ha. Five replicate plots of each dispenser treatment spaced by at least 15 m were randomly established throughout the orchard.

Observations of moth orientation to dispensers were conducted on 21 nights between 22 May and 27 June during the first generation flight, and on seven nights between 7 and 26 July during the second generation flight. Observations were conducted for approximately 2 h each night between 21:00 and 23:00 hours. An observer rotated among plots conducting 20 min observational bouts per treatment replicate such that multiple treatments were observed on a given night. The order of observations across treatments was randomized each night. The number of *C. pomonella* observed orienting to dispensers and reaching approximately within 20 cm of dispensers was recorded. The sex of moths was not recorded. Data were dictated into a hand-held microcassette audio recorder by an investigator standing 0.75 m from the semiochemical source under observation. Observations after dusk employed night-vision goggles (Rigel, Model 3250, DeWitt, IA) as described by Stelinski et al. (2004).

Dispenser release rates

Isomate-C® Plus and the PVC dispensers, TRE 9923 and TRE 9904, were aged in an apple orchard situated near Wenatchee, WA (47.42°N, 120.30°W) and collections (n = 4) were made every 2 weeks from 3 May to 6 September 2006. Dispensers were shipped frozen to the Food and Environmental Quality Laboratory, Richland, WA and kept at −15°C. All dispensers were allowed to equilibrate at room temperature for 24 h prior to volatile collection. The volatile collection apparatus consisted of compressed air flowing through Teflon tubing connected to a 1-l Teflon collection chamber and to a glass tube containing an adsorbent polyurethane foam cartridge (Supelco, Bellefonte, PA). Individual dispensers were suspended on Teflon tape within the collection chamber along with a small piece of glass microfiber filter paper treated with myristic acid methyl ester as the surrogate standard. Volatile collections were made for 2 h at 20°C with a flow rate of 10 l/min. The filter paper and foam cartridge were solvent extracted with 10% ethyl acetate and 90% hexane. Solvent rinses of the Teflon surfaces were also performed and added to the extraction solvent. Samples were concentrated by rotary evaporation to approximately 2 ml and re-adjusted to 10 ml with 100% hexane. Extracts were then analysed using an Agilent 6890N Gas Chromatograph with 5973N Mass Selective Detector (MSD) and an Agilent 7683 auto sampler. Operating procedures and GC conditions have been previously detailed in Tomaszewska et al. (2005). The quantification of residues in the extract was performed by electronic peak area measurement and comparison to the linear regression from a minimum of four standards in the concentration range of sample extracts. All samples were bracketed with external calibration standards during the analytical set. For each analytical set, linearity and calibration standards were used to construct the calibration curve.

Statistical analyses

Count data were transformed (square root) to normalize their distributions prior to analysis of variance (ANOVA). The proportion of fruit injury and traps baited with virgin females catching male moths were subjected to an angular transformation prior to ANOVA. The average time spent by moths orienting to semiochemical dispensers in the field was analysed by ANOVA. Differences among means in significant ANOVA's were separated using the LSD test, $P < 0.05$ (SAS Institute 2000). Linear regression was used to describe the relationship between dispenser age and their volatile emission under laboratory conditions. ANCOVA was used to compare the intercept and slopes of regressions. A two sample *t*-test was used to compare the emission rate of new dispensers.

Results

Small-plot study

All dispensers significantly reduced male captures in both lure- and female-baited traps over the entire season compared with the untreated control (Table 1). No significant differences were found among dispensers for the cumulative captures of males in virgin-female-baited traps during either moth flight period. Male moth catch in lure-baited traps was significantly lower in the second flight in TRE 9904 plots treated with 1000 dispensers per ha than plots treated with CheckMate® CM dispensers (Table 1).

Large-plot studies

Mean cumulative male moth catches in codlemone-baited traps were not significantly different among dispenser treatments in Washington during 2006 (Table 2). All dispenser treatments significantly reduced moth catches compared with the untreated control in Michigan. In addition, cumulative moth catches in plots treated with either TRE 9923 or TRE 9904 were significantly lower than catches in Isomate®-C Plus-treated plots during the first moth flight (Table 2). No significant difference in levels of fruit injury at either mid-season or prior to harvest was found among dispenser treatments in either state. All dispenser treatments in Michigan had levels of fruit injury significantly lower than found in the untreated controls.

Field observations of moth approach to dispensers

A total of 43, 35 and 27 moths were observed orienting to TRE 9923 (codlemone only), TRE 9904 (codlemone + pear ester) and Isomate®-C Plus,

Table 1 Summary of male moth catches in five delta traps baited with virgin females (VF) and one trap baited with a synthetic pheromone lure (PH) evaluating several experimental PVC dispensers (TRE no.) loaded with pheromone alone or in combination with pear ester (PE) vs. the commercial pheromone CheckMate® CM dispenser, in small plot studies in apple, Wapato, WA, n = 4, 2006

Treatment (dispensers per ha)	First flight: Mean ± SE Prop. VF traps Catching per time period	First flight: Mean ± SE Cumulative male catch, 5 VF traps	First flight: Mean ± SE Cumulative male catch, PH trap	Second flight: Mean ± SE Prop. VF traps Catching per time period	Second flight: Mean ± SE cumulative male catch, 5 VF traps	Second flight: Mean ± SE cumulative male catch, PH trap
Untreated	0.26 ± 0.08a	11.8 ± 3.7a	50.3 ± 5.4a	0.44 ± 0.11a	81.8 ± 35.1a	192.0 ± 20.2a
PH: TRE 9923 (1000)	0.04 ± 0.03b	1.0 ± 0.7b	2.3 ± 1.9b	0.10 ± 0.02b	3.8 ± 1.3b	20.3 ± 14.3bc
PH + PE: TRE 9904 (500)	0.02 ± 0.02b	0.5 ± 0.5b	2.5 ± 2.5b	0.06 ± 0.03b	4.0 ± 1.5b	26.5 ± 20.9bc
PH + PE: TRE 9904 (1000)	0.01 ± 0.01b	0.3 ± 0.3b	0.5 ± 0.3b	0.06 ± 0.02b	1.8 ± 0.5b	3.0 ± 0.4c
PH: CheckMate CM (500)	0.00 ± 0.00b	0.0 ± 0.0b	5.0 ± 2.2b	0.06 ± 0.03b	4.0 ± 2.7b	53.0 ± 24.5b
ANOVA	$F_{4,15}$ = 8.01 P < 0.01	$F_{4,15}$ = 12.50 P < 0.0001	$F_{4,15}$ = 24.07 P < 0.0001	$F_{4,15}$ = 7.67 P < 0.01	$F_{4,15}$ = 13.19 P < 0.0001	$F_{4,-15}$ = 12.85 P < 0.0001

Column means within each study followed by a different letter were significantly different, P < 0.05, LSD test.

Table 2 Summary of moth catches and levels of fruit injury from codling moth in large plot studies conducted with experimental PVC dispensers loaded with pheromone alone (PH) or a combination of pheromone and pear ester (PE) vs. the pheromone dispenser Isomate-C Plus in Washington (2006) and Michigan (2007)

Dispenser[1]	Mean ± SE moth catch: First flight	Mean ± SE moth catch: Second flight	Mean ± SE % fruit injury: Mid-season	Mean ± SE % fruit injury: Pre-harvest
Brewster, WA 2006				
PH: TRE 9923	38.0 ± 14.4	21.7 ± 6.5	0.19 ± 0.07	0.36 ± 0.15
PH + PE: TRE 9904	55.0 ± 19.8	30.2 ± 17.8	0.28 ± 0.20	0.39 ± 0.15
PH + PE: TRE 9940	51.6 ± 10.7	11.7 ± 4.5	0.00 ± 0.00	0.50 ± 0.29
PH: Isomate-C Plus	89.6 ± 36.1	30.5 ± 11.5	0.13 ± 0.11	0.39 ± 0.21
ANOVA	$F_{3,9}$ = 1.15 P = 0.38	$F_{3,9}$ = 0.85 P = 0.50	$F_{3,9}$ = 1.83 P = 0.21	$F_{3,9}$ = 0.05 P = 0.98
Grand Rapids, MI 2007				
Untreated	1.8 ± 0.4a	5.7 ± 2.0a	0.80 ± 0.70	11.3 ± 10.7a
PH: TRE 9923	0.1 ± 0.04c	0.9 ± 0.4b	0.05 ± 0.03	0.08 ± 0.06b
PH + PE: TRE 9904	0.1 ± 0.1c	1.7 ± 0.5b	0.08 ± 0.06	0.06 ± 0.06b
PH: Isomate-C Plus	0.5 ± 0.1b	0.6 ± 0.2b	0.13 ± 0.05	0.09 ± 0.04b
ANOVA	$F_{3,9}$ = 5.64 P < 0.05	$F_{3,9}$ = 4.33 P < 0.05	$F_{3,9}$ = 0.43 P = 0.61	$F_{3,9}$ = 3.98 P < 0.05

Column means within each study followed by a different letter were significantly different, P < 0.05, LSD test.

respectively, over the 28 nights. Nearly, all (97%) moths orienting to dispensers exhibited typical upwind anemotaxis until they approached within 10–15 cm from the source when they broke off plume following and subsequently flew upwind. Only three moths contacted dispensers, one moth to each dispenser type. The mean (±SEM) durations of observed visits of moths to TRE 9923, TRE 9904 and Isomate®-C Plus dispensers were 15.1 ± 3.1, 15.4 ± 3.1 and 13.2 ± 3.5 s, respectively, with no significant differences between treatments ($F_{2,101}$ = 0.11, P = 0.90).

Dispenser release rates

Volatile capture declined for all field-aged dispensers over the course of the season (fig. 1). The Isomate®-C Plus dispenser had an initial high rate of codlemone release followed by a fairly shallow linear decline over the 18-week period (fig. 1a). The TRE 9923 dispenser had a similar shallow linear emission profile for codlemone with the Isomate-C® Plus dispenser from 2 to 18 weeks (ANCOVA; intercept, P = 0.16; slope, P = 0.60; combined regression: y (mg) = 0.14–0.005 weeks, r^2 = 0.62). However, the

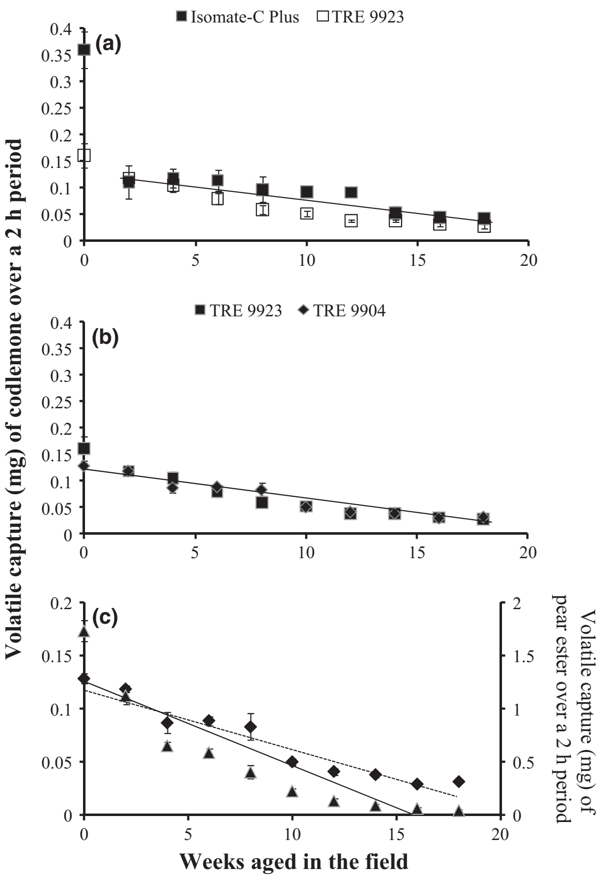

Fig. 1 Regressions of mean (±SE) volatile recaptures (mg) over a 2-h collection period under laboratory conditions as a function of dispenser's field age: (a) codlemone released from Isomate-C Plus (solid squares) and TRE 9923 dispensers (open squares); (b) codlemone released from TRE 9923 (open squares) and TRE 9904 dispensers (solid diamonds); and (c) codlemone (diamonds with fitted dashed line) and pear ester (triangles with fitted solid line) released from TRE 9904 dispensers.

new dispensers exhibited significantly different emission rates, $t_6 = 4.83$, $P < 0.01$. The emission rate of codlemone was also similar between TRE 9923 and the dual-component dispenser, TRE 9904 (ANCOVA; intercept, P = 0.15; slope, P = 0.13; combined regression: y (mg) = 0.12–0.006 weeks, $r^2 = 0.80$) (fig. 1b). In sharp contrast, the emission rate of codlemone and pear ester from the TRE 9904 dispenser differed significantly, ANCOVA's, P-values <0.0001 for intercept and slope (fig. 1c). The emission rate (mg) of pear ester was nearly 10-fold higher than codlemone from new dispensers, and the decline in emission rate (y) with time was steeper for pear ester (y = 1.24–0.08 weeks, $r^2 = 0.79$) than for codlemone (y = 0.12–0.006 weeks, $r^2 = 0.86$). Dispensers field-aged for 18 weeks released nearly identical levels of each volatile (fig. 1).

Discussion

The new PVC dispenser formulations loaded with codlemone alone or with a blend of codlemone and pear ester performed similarly to other codlemone dispensers in a series of field trials which measured levels of disruption of male moth capture in lure and female baited traps. The emission rates of codlemone from the PVC dispensers were similar to Isomate®-C Plus over the entire season. Interestingly, both the single pheromone alone and dual-component PVC dispensers outperformed Isomate®-C Plus during the first half of the season during 2007 in Michigan. Assessing the significant difference found for pheromone trap catch suppression in the second flight of 2006 between the dual-component PVC TRE 9904 dispensers and CheckMate® CM is more problematic, because of the unequal dispenser density. This is suggested by the lack of difference between the PVC TRE 9904 and CheckMate® CM dispensers when both were compared at a similar density. However, the performance of dispensers applied at 500 or 1000 per ha have typically been similar for disruption of codling moth (Epstein et al. 2006).

The dual-component PVC dispenser, TRE 9904, released pear ester at a much higher rate than codlemone initially, but this difference declined continuously over the season. A similar higher emission of pear ester than codlemone was reported with the use of paraffin wax dispensers (Stelinski et al. 2007). Nevertheless, few differences were found in the disruption of traps or calling females when data for the 2006 and 2007 experiments were summed over approximate 8-week periods for dispensers loaded with or without the addition of pear ester. This is in contrast to a loss in the superior effectiveness of dual-component dispensers relative to Isomate®-C Plus dispensers reported previously after only 4 weeks (Stelinski et al. 2007). Levels of moth catches in pheromone and virgin-female traps remained >2-fold higher in Washington small plots treated with TRE 9923 vs. TRE 9904 during the second moth flight. Unfortunately, our experimental design was likely under replicated and the high variability in moth catches that occurred among plots precluded significant mean separations between dispenser treatments unless differences were >17-fold. In contrast, the use of 10 traps per plot in Michigan allowed statistical separation of means that differed

<4-fold. Finally, the associated difficulties in maintaining virgin female traps during hot summer periods suggested that traps baited with 0.01 mg codlemone lures which release codlemone at levels similar to a calling female might be a better alternative to assess disruption in field trials (Bäckman et al. 2007).

Pear ester is known to increase the behavioural response of male *C. pomonella* to its sex pheromone (Knight et al. 2005). This plant volatile elicits strong responses from antennal neurons in the peripheral nervous system (De et al. 2004; Ansebo et al. 2005) and from antennal lobe neurons involved with central processing (Trona et al. 2011). Interactive effects, for example, additive or synergistic, between sex pheromone and plant volatile chemoreception may increase male behavioural response, given that codlemone and pear ester in some cases activate common receptors (De et al. 2004; Ansebo et al. 2005). Disruption of male *C. pomonella* by point sources of pheromone that release fractions of mg of active ingredient per day and that are applied at *ca*. 1000 per ha is thought to occur by initial attraction of males to the vicinity of dispensers (e.g. 'false-trail following') followed by deactivation following overexposure of sensory neurons (Stelinski et al. 2006; Miller et al. 2010). Our direct observations of feral moth behaviour in the field proved that *C. pomonella* approached dual-component dispensers at frequencies similar to those observed in response to Isomate®-C Plus. Therefore, we hypothesized that deployment of dispensers that release both codlemone and pear ester simultaneously would improve the level of disruption as compared with those releasing pheromone alone. However, our current results do not clearly support this hypothesis.

Given the overall effectiveness of dispensers releasing codlemone alone in these experiments, a slight improvement caused by the additional release of pear ester may have been difficult to demonstrate in the field under the population densities observed and the suppressive insecticide regimes used. Previous investigations did suggest greater disruption of *C. pomonella* in plots treated with dispensers releasing both codlemone and pear ester compared with those treated with dispensers releasing codlemone only (Light and Knight 2005; Stelinski et al. 2007). Also, preliminary results suggest that the amount of codlemone released from dispensers can be drastically reduced, while maintaining equivalent efficacy, when those dispensers release codlemone and pear ester simultaneously (Stelinski et al. 2007). The successful disruption of codling moth achieved in our current studies with PVC dispensers supports further testing of various release rates and ratios of pear ester and codlemone under diverse population densities and within varying crop systems.

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